Gravity versus Quantum theory: Is electron really pointlike?

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Abstract

Quantum theory claims that electron is pointlike and structureless. Contrary, the consistent with Gravity Kerr-Newman (KN) electron model displays an extended structure of the Compton size $r_c = \hbar/m$. We obtain that there is no real conflict between the extended Gravitating electron and a Quantum electron "dressed" by virtual particles. In the same time the KN model indicates new important details of the electron structure and sheds new light on some old puzzles of quantum theory. In particular, the KN Gravity predicts that electron forms a disklike vacuum bubble bounded by a closed string, which could probably be detected by the novel experiments. If it will be confirmed, it would be of primary importance for foundations of Quantum theory and unification of Quantum theory with Gravity.

"Nobody understands quantum mechanics."
Richard Feynman (1965), [1]

Modern physics is based on Quantum theory and Gravity. The both theories are confirmed experimentally with great precision. Nevertheless, they are conflicting and cannot be unified in a whole theory. In this essay we discuss one of the principal contradictions, the question on the shape and size of electron.

Quantum theory states that electron is pointlike and structureless. In particular, Frank Wilczek writes in [2]: "...There's no evidence that electrons have internal structure (and a lot of evidence against it)", while the superstring theorist Leonard Susskind notes that electron radius is "...most probably not much bigger and not much smaller than the Planck length..", [3]. [1] This point of view is supported by experimental evidences, which have not found the electron structure down to $10^{-16}cm$.

The widespread opinion that the range of interaction for gravitational field is "tremendously weak" and becomes compatible to other forces only at Planck scale, [4], is inspired by the Schwarzschild relation $r_g = 2m$. The Kerr geometry turns this relation into inverse one, $r_g \sim J/m$, which points out that the range of interaction may be extended to radius of the Kerr singular ring, $a = J/m$. Gravitational field of the Kerr solution concentrates in a thin vicinity of the Kerr ring, forming a type of "gravitational waveguide", or string. For electron, the Kerr field may be extended to the Compton radius $r_c = \hbar/(2m)$, which corresponds to the size of a "dressed" electron. We argue here that the Kerr string is an element of the extended electron structure.

In 1968 Carter obtained that the KN solution for the charged and rotating black holes has $g = 2$ as that of the Dirac electron, [5, 6], which initiated development of the electron models based on the KN solution [5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20].

In the units $c = \hbar = G = 1$, mass of electron is $m \approx 10^{-22}$, while $a = J/m \approx 10^{22}$. Therefore, $a >> m$, and the black hole horizons disappear, opening the Kerr singular ring which is a branch line of the twovalued Kerr spacetime. Development of the KN electron models for four decades formed severe lines of investigation:

(a) First ("thin shell") model was suggested by Israel, [7], who truncated the "negative" fold of metric, forming a rotating disk spanned by the

[1] Author thanks Don Stevens for these references and conversation.

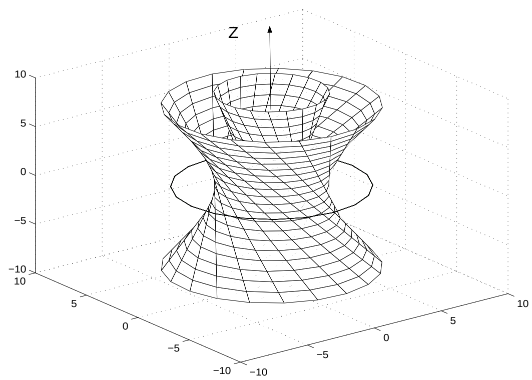

Figure 1: Vortex of the Kerr congruence. Twistor null lines are focused on the Kerr singular ring, forming a circular gravitational waveguide, or string with lightlike excitations.

Kerr singular ring. Hamity [21] showed that the disk is rigidly rotating.

(b) López [12] removed the Kerr singular ring together with negative fold, forming a rotating disklike bubble with a flat interior.

(c) "Microgeon" models [8, 9, 10, 22] evolved into $4D$ string models [11, 13, 14, 15, 19, 23, 24, 25, 26, 27].

(d) Superconducting bag models [16, 28] based either on nonlinear electrodynamics [18, 29], or on the Higgs field model [16, 30]

(e) Gravitating soliton model [20] is development of the type (c) and (d) models.

All these models unambiguously indicated Compton radius of the electron. Note, that the Compton radius plays also peculiar role in the Dirac theory, as a limit of localization of the wave packet. Localization beyond the Compton zone creates a "zitterbewegung" affecting "...such paradoxes and dilemmas, which cannot be resolved in frame of the Dirac electron theory..." (Bjorken and Drell, [31]). Dirac wrote in his Nobel Prize Lecture : "The variables α (velocity operators, AB) also give rise to some rather unexpected phenomena concerning the motion of the electron. .. It is found that an electron which seems to us to be moving slowly, must actually have a very

high frequency oscillatory motion of small amplitude superposed on the regular motion which appears to us. As a result of this oscillatory motion, the velocity of the electron at any time equals the velocity of light."

Mass without mass. The puzzle of "zitterbewegung" and the known processes of annihilation of the electron-positron pairs brought us in 1971 to the Wheeler "geon" model of "mass without mass" [32]. In [22] we considered a massless particle circulating around z-axis. Its local 4-momentum is lightlike,

$$p_x^2 + p_y^2 + p_z^2 = E^2, \tag{1}$$

while the effective mass-energy was created by an averaged orbital motion,

$$< p_x^2 > + < p_y^2 >= \tilde{m}^2. \tag{2}$$

Averaging (1) under the condition (2) yields

$$< p_x^2 + p_y^2 + p_z^2 >= \tilde{m}^2 + p_z^2 = E^2. \tag{3}$$

Quantum analog of this model corresponds to a wave function $\psi(\vec{x}, t)$ and operators, $\vec{p} \to \hat{\vec{p}} = -i\hbar\nabla, \quad \hat{E} = i\hbar\partial_t$. From (1) and (2) one obtains two wave equations:

$$(\partial_x^2 + \partial_y^2)\psi = \tilde{m}^2\psi = (\partial_t^2 - \partial_z^2)\psi, \tag{4}$$

which may be separated by the ansatz

$$\psi = \mathcal{M}(x, y)\Psi_0(z, t). \tag{5}$$

The RHS of (4) yields the usual equation for a massive particle, $(\partial_t^2 - \partial_z^2)\Psi_0 = \tilde{m}^2\Psi_0$, and the corresponding (de Broulie) plane wave solution

$$\Psi_0(z, t) = \exp\frac{i}{\hbar}(zp_z - Et), \tag{6}$$

while the LHS determines the "internal" structure factor

$$\mathcal{M}_\nu = \mathcal{H}_\nu(\frac{\tilde{m}}{\hbar}\rho)\exp\{i\nu\phi\}, \tag{7}$$

in polar coordinates ρ, ϕ, where $\mathcal{H}_\nu(\frac{\tilde{m}}{\hbar}\rho)$ are the Hankel functions of index ν. $\mathcal{M}_\nu$ are eigenfunctions of operator $\hat{J}_z = \frac{\hbar}{i}\partial_\phi$ with eigenvalues $J_z = \nu\hbar$. For electron we have $J_z = \pm\hbar/2, \quad \nu = \pm 1/2$, and the factor

$$\mathcal{M}_{\pm 1/2} = \rho^{-1/2}\exp\{i(\frac{\tilde{m}}{\hbar}\rho \pm \frac{1}{2}\phi)\} \tag{8}$$

creates a singular ray along z-axis, which forms a branch line, and the wave function is twovalued.

There exits also the corresponding spinor model [22] generating Dirac equation from the initially massless one.

The Kerr string. Principal problem of this model was the weakness of the Schwarzschild gravitational field, strength of which fails about 22 orders. The works [5, 6, 7] appeared as a stunning surprise, which determined all subsequent development of the type (c) models. The Kerr gravitational field is concentrated near the Kerr singular ring and forms a *gravitational waveguide* for traveling waves. Indeed, it was recognized soon that the Kerr singular ring is a type of gravitational string [11, 13, 23, 25], while the traveling waves are stringy excitations.[2] It has been shown that the Kerr metric provides self -consistency of the spinning geon model [8]. First approximate solutions were considered in [9], while the exact solutions for electromagnetic excitations on the Kerr-Schild background represented a very hard problem [33] and were obtained much later [27, 34, 35, 36]. It has been shown that any wave excitation creates some 'axial' singular ray (see Fig.2) similar to the 'axial' singular ray of the geon model.

Gravitating KN soliton. The KN soliton model [20] represents a field version of the bubble model (b). Surface of the bubble is fixed by the Kerr radial coordinate $r = r_e = e^2/(2m)$, and forms an oblate disk of the Compton radius $r_c \approx a = \hbar/(2m)$.

Gravitational field is regularized by a chiral field model, $U(1) \times \tilde{U}(1)$, which provides a phase transition from the external KN 'vacuum state', $V_{ext} = 0$, to a flat internal 'pseudovacuum' state, $V_{int} = 0$. Electromagnetic field is regularized by the Higgs mechanism of broken symmetry, similarly to other models of electroweak theory [4, 37, 38, 39]. The model exhibits two essential peculiarities:

- the Kerr ring is regularized, forming on the border of bubble a closed relativistic string of the Compton radius r_c and a quantized loop of electromagnetic potential $\oint eA_\phi^{(str)} d\phi = -4\pi ma$, which determines total spin, $J = ma = n/2,\ n = 1, 2, 3, ...,$

- the Higgs field inside the bubble forms a coherent vacuum state oscillating with frequency $\omega = 2m$.

[2] It was shown in [13] that structure of the field around the Kerr ring is similar to the field around a heterotic string.

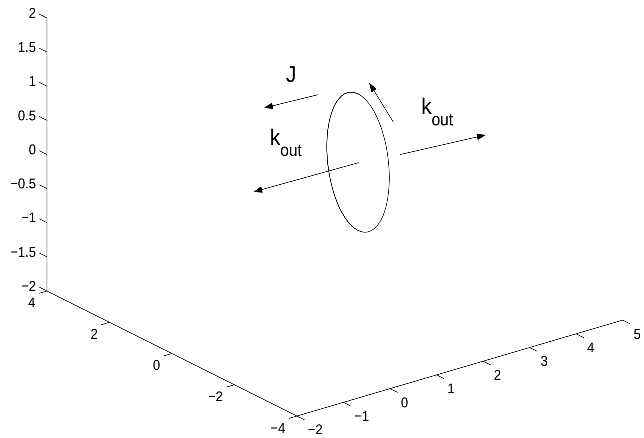

Figure 2: Skeleton of the Kerr geometry [27] formed by the topologically coupled "circular" and "axial" strings.

The KN soliton forms a regular background for stringy excitations described by the type (c) models, while the wave excitations of the Kerr string are determined by the exact time-dependent Kerr-Schild solutions, [9, 27, 34, 36].

Does the KN model of electron contradict to Quantum Theory? It seems "yes", if one speaks on the "bare" electron. However, in accordance with QED, vacuum polarization creates in the Compton region a cloud of virtual particles forming a "dressed" electron. This region gives contribution to electron spin, and performs a procedure of renormalization, which determines physical values of the electron charge and mass, [31, 40, 41]. Therefore, speaking on the "dressed" electron, one can say that the real contradiction between the KN model and the Quantum electron is absent.

Dynamics of the virtual particles in QED is chaotic, which allows one to separate conventionally it from the "bare"electron. On the other hand, the vacuum state inside the KN soliton model forms a *coherent state,* joined with the closed Kerr string. It represents an 'internal' structure which cannot be separated from a "bare" particle, but should be considered as *integral whole of the extended electron.*

We should still comment the absence of experimental exhibitions of the electron structure. First, it may be caused by a specific complex structure

of the Kerr geometry [9, 14, 42, 43, 44, 45, 46]: the KN solution appears as a real slice of a pointlike source positioned in complex region.[3] Fourier transform of the complex source is very similar to Fourier image of the real pointlike source, which may result in its pointlike exhibition in the momentum space. Alternative explanation (discussed in [15]) is related with the lightlike singular beams (see Fig.2.), accompanying any wave excitation of the Kerr geometry,[26, 27, 34, 35]. Finally, the pointlike interaction may simply be related with the contact character of the string-string interactions.

Conclusion: The KN gravity sheds a new light on the possible role of Gravity in the structure of Quantum theory. If the electron has really the predicted closed string on the boundary of a disklike bubble, it should apparently be detected experimentally by a novel effective tool – the "nonforward Compton scattering" [49, 50, 51, 52].

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